Physical and Life Sciences Directorate
Axion Dark Matter Experiment (ADMX)

Feb 9th, 2011

Gianpaolo Carosi (ADMX PI)

Advanced Detector Group

Physical and Life Sciences

Lawrence Livermore National Laboratory

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Overview of ADMX

"Phase I" operations (FY 2010):

- First-year "medium resolution" data published (PRL)
- Chameleon search results published (PRL)
- Hidden-sector-photon search results published (PRL)

"Phase I" supplemental operations (FY 2011):

- First-year-data "high-resolution" analysis in progress
- Instrumentation / Receiver paper (in draft).
- RF-Test stand design and construction

"Phase II" project plan (FY 2011….):

- Structure of Phase II project
- ADMX in the recent PASAG report
- Move-of-experiment to the University of Washington
- LLNL's role in ADMX Phase II

Conclusions

ADMX collaboration

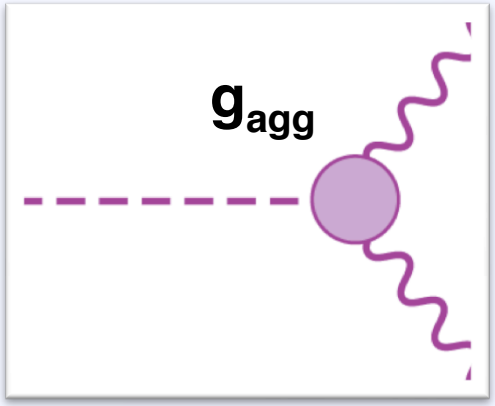
- Lawrence Livermore National Laboratory
- Gianpaolo Carosi (PI @ LLNL), Darrell Carter, Chris Hagmann, Darin Kinion,
- Karl van Bibber currently @ Naval Postgraduate School, Monterey, CA
- University of Washington
- Leslie Rosenberg*spokesman, Gray Rybka, Michael Hotz, Andrew Wagner, Doug Will,
- Jesse Heilman, Kyle Tracy, Miguel Morales
- University of Florida
- David Tanner, Pierre Sikivie, Neil Sullivan, Jeff Hoskins, Jungseek Hwang,
- Catlin Martin
- National Radio Astronomy Observatory
- Richard Bradley
- University of California, Berkeley
- John Clarke
- Sheffield University
- Edward Daw

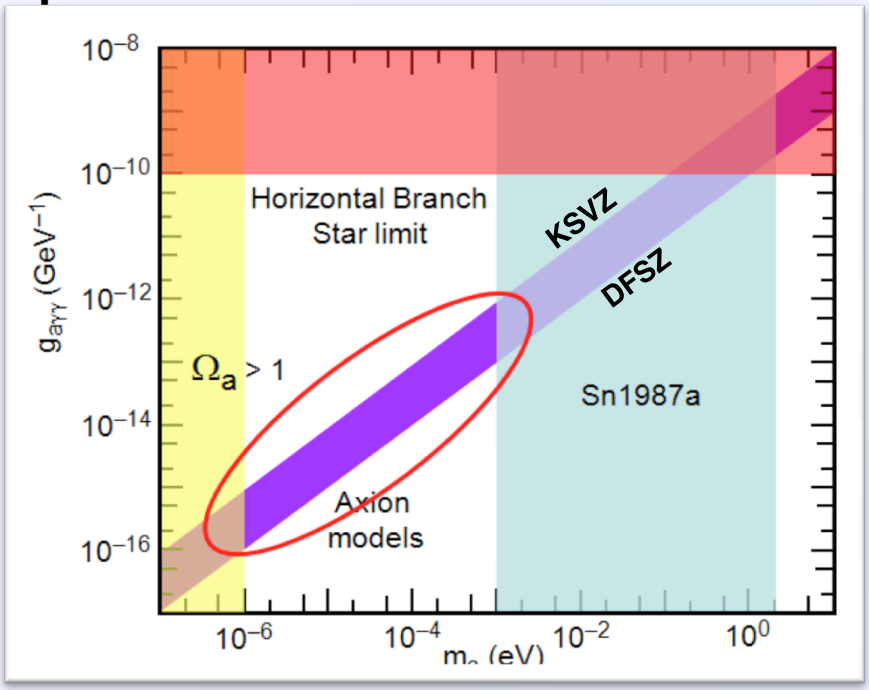
The axion.

It comes from the "Pecci-Quinn solution" to enforce strong-CP

It's a pseudoscalar (π^0-like), extremely light and weakly coupled

2γ coupling (Primakoff effect) : Key to possible detection

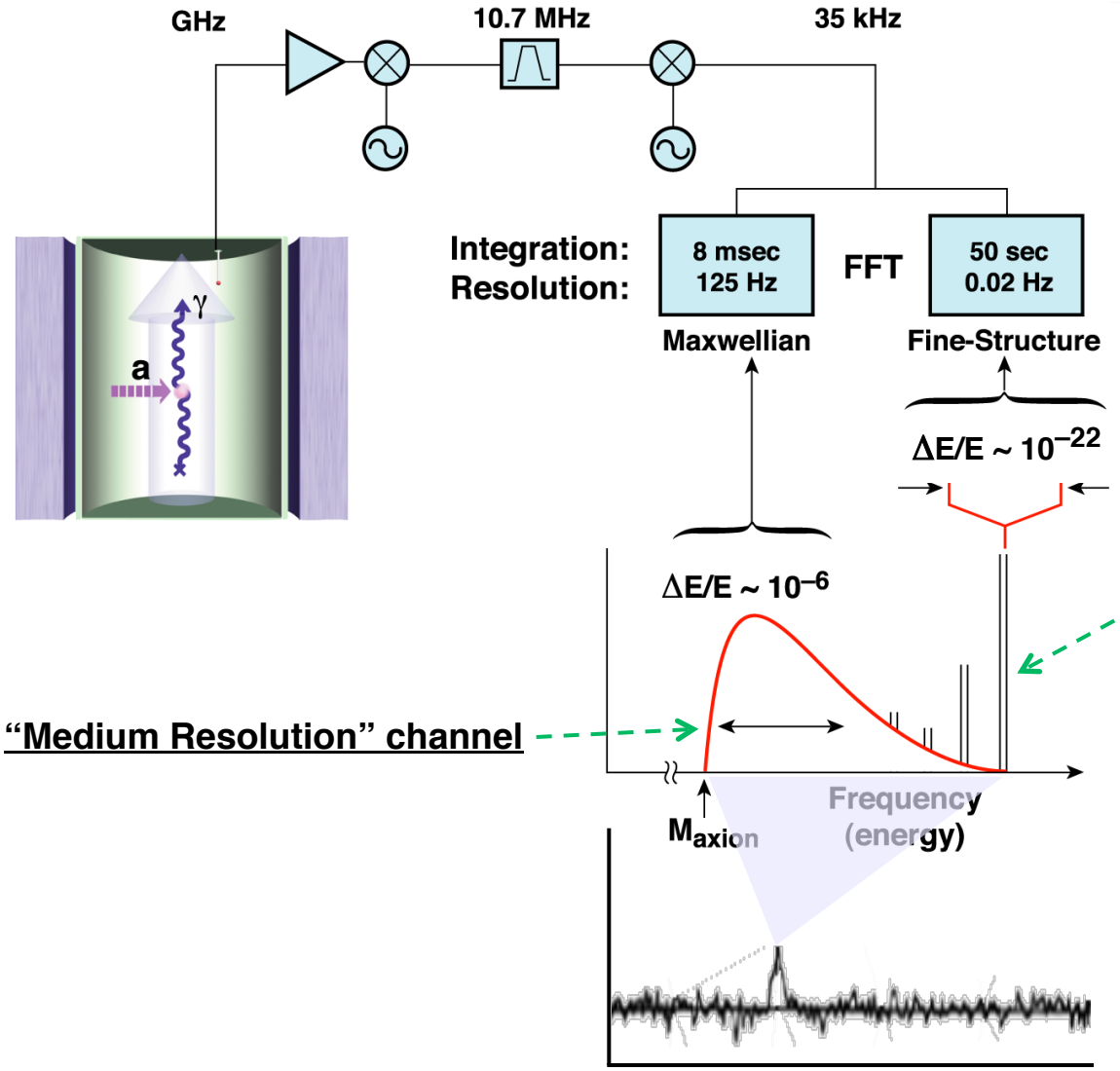




The axion remains a very attractive dark-matter candidate (affirmed by HEPAP, DMSAG, etc.)

The ADMX axion search is "definitive" and relatively inexpensive

The Axion Dark Matter eXperiment



Local Milky Way density:

$\rho_{halo} \sim 450\ MeV/cm^3$

Thus for $m_a \sim 10\ \mu eV$:

$\rho_{halo} \sim 10^{14}\ cm^{-3}$

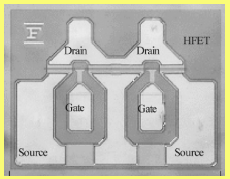
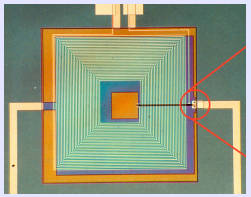
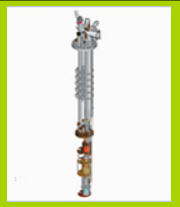
$\beta_{virial} \sim 10^{-3}$:

$\lambda_{De\ Broglie} \sim 100\ m$

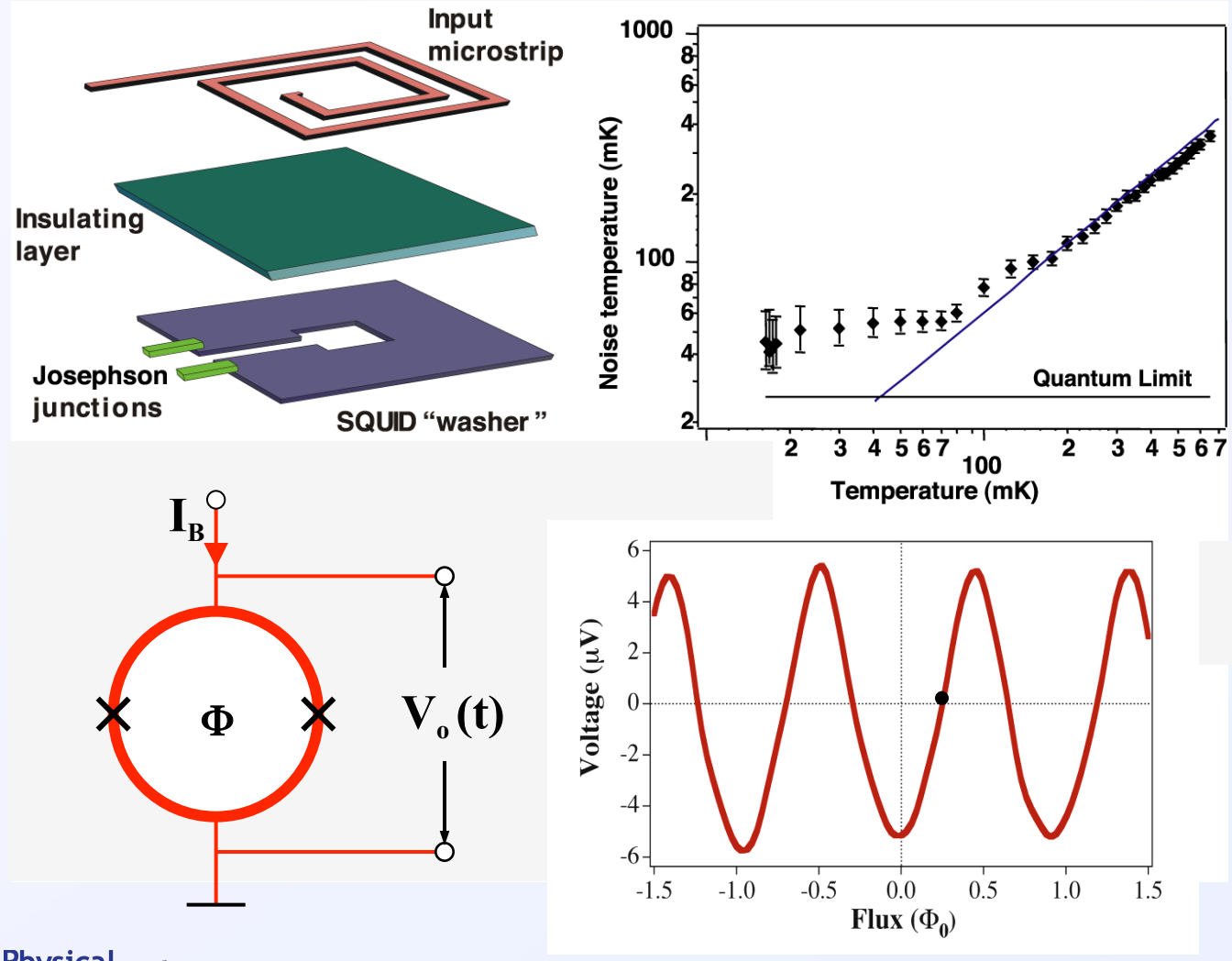
$\Delta\beta_{flow} \sim 10^{-11}$:

$\lambda_{Coherence} \sim 1000\ km$

The Axion Dark Matter eXperiment

Stage	**Phase 0**	**Phase I**	**Phase II**
Technology	HEMT; Pumped LHe 	Replace w. SQUID 	Add Dilution Fridge 
T_{phys}	2 K	2 K	100 mK
T_{amp}	2 K	1 K	100 mK
$T_{sys} = T_{phys} + T_{amp}$	4 K	3 K	200 mK
Scan Rate $\propto (T_{sys})^{-2}$	1 @ KSVZ	1.75 @ KSVZ **OR** 0.75 x KSVZ	5 @ DFSZ **AND !** DFSZ
Sensitivity Reach $g^2 \propto T_{sys}$	KSVZ		

Phase I & II Upgrade path: Quantum-limited SQUID-based amplification



- SQUIDs have been measured with T_N ~50 mK
- Near quantum–limited noise
- This provides an enormous increase in ADMX sensitivity

What are the "Phase I" and "Phase II" Upgrades?

In 2000 we briefed SAGENAP on a proposed upgrade of ADMX, to result in a "definitive" experiment

SAGENAP strongly endorsed the upgrade, but recommended it proceed in two phases:

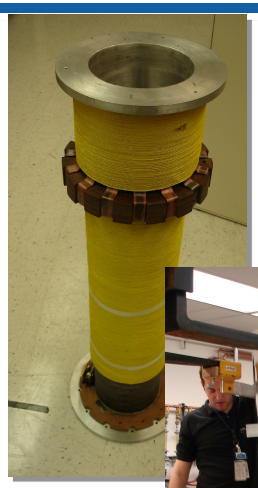
Phase I: Retrofit SQUID amplifiers first, but stay at 2K physical temperature

Phase II: Once SQUIDs work in situ, retrofit with the dilution refrigerator for 100 mK physical temperature (re-endorsed by P5, HEPAP, PASAG etc.)

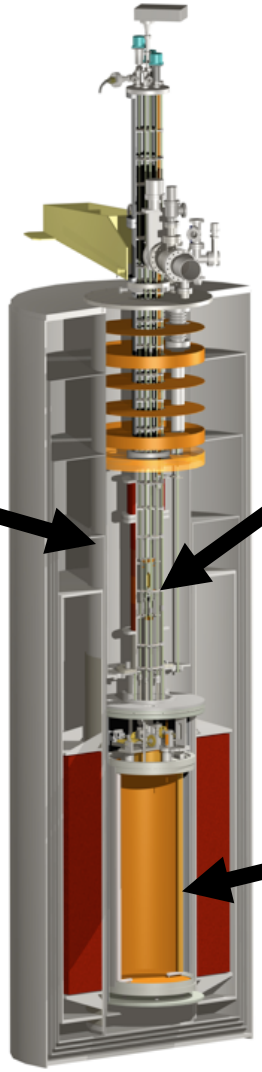
Phased approach "more prudent"; "Don't stay away from data too long"

Results of Phase I: Successfully operated SQUID amplifier near 8 T field!

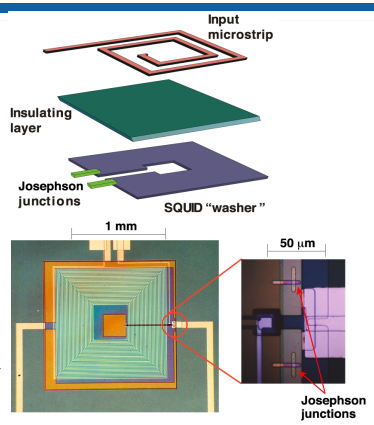
Phase I upgrade (Started data taking in May 2008)



Field compensation magnet for SQUIDs



SQUID amplifier



Brief timeline of ADMX Phase I

- First major down-time for Phase I Upgrade (SQUIDS) (2004-2008)
- First cool-down of Phase I Upgrade (fall 2007)
- Start of Phase I Upgrade operations at third cool-down (April 2008)
- "Short access" starts 8 July 08; cash-flow squeeze delays re-cooling until September 2008
- Sept 2008-Dec 2008 Operations
- Jan 2009 – Feb 2009 Access to fix thermal issues
- March 2009 – June 2009 Operations:
  Major milestones achieved:
  (1) Heat load at design value.
  (2) Magnetic field bucking system operational.
  (3) SQUID receiver chain operational.
  (4) Production data-taking in progress.
- July 2009 Access to fix tuning mechanism
- August 2009 Operations
- Sept 2009 Access to repair receiver chain and expand tuning range
- Jan 2010 Operations milestone achieved: (5) Published PRL on first-year operations.
- Ceased Phase I data taking April 2010… moved into current analysis phase.

ADMX Phase I: Accomplishments to date.

Successfully operated experiment with SQUID amp near 7 Tesla field!

PRL **104,** 041301 (2010) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2010

SQUID-Based Microwave Cavity Search for Dark-Matter Axions

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(Received 27 October 2009; published 28 January 2010)

Axions in the μeV mass range are a plausible cold dark-matter candidate and may be de
conversion into microwave photons in a resonant cavity immersed in a static magnetic field.
first result from such an axion search using a superconducting first-stage amplifier (SQUI
conventional GaAs field-effect transistor amplifier. This experiment excludes KSVZ dark-
with masses between 3.3 μeV and 3.53 μeV and sets the stage for a definitive axion search
quantum-limited SQUID amplifiers.

DOI: 10.1103/PhysRevLett.104.041301 PACS numbers: 95.35.+d, 14.

Received: Oct 27th, 2009
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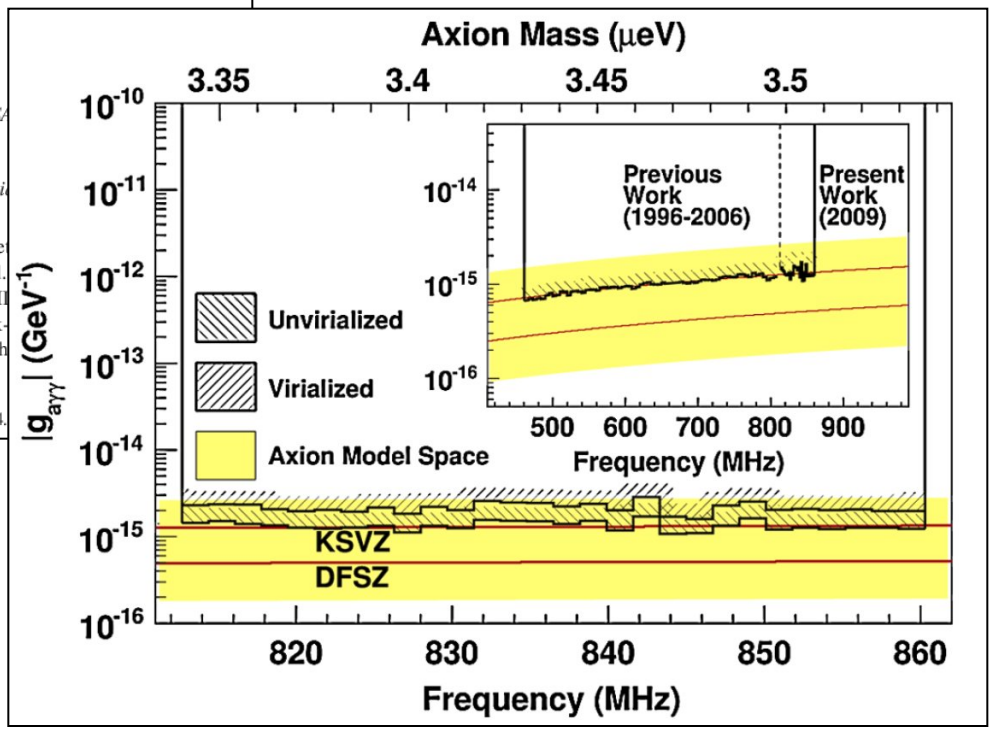
Published: Jan 29th, 2010
DOI: 10.1103/PhysRevLett.104.041301



Covered 812 – 860 MHz = 48 MHz

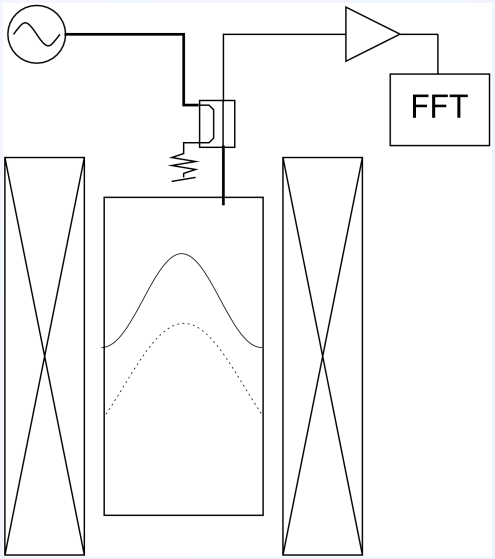
Total Run Time: 19 months

Continuous Data Collecting: 8 months

Phase I operations: Possible to search for other light bosons! "Chameleons"& hidden-sector photons (1)

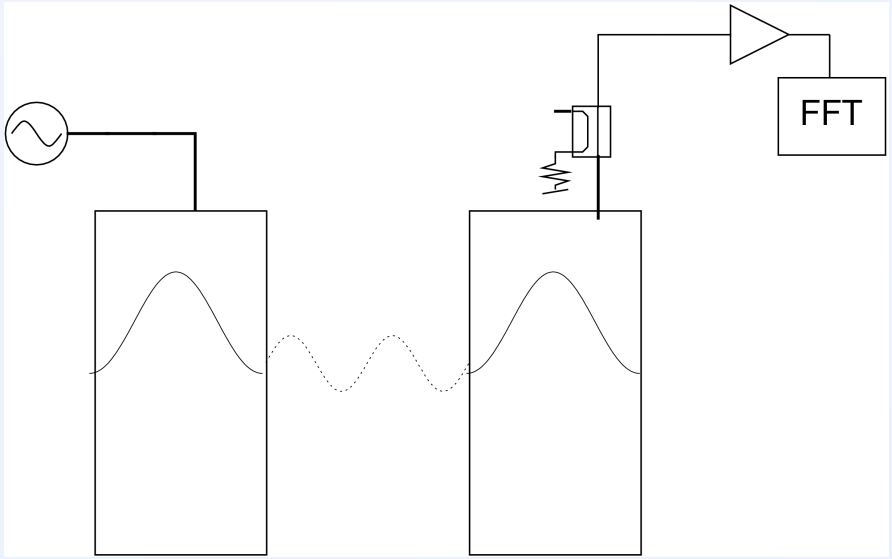
Chameleons

Scalars/pseudoscalars that mix with photons, and are trapped by cavity walls. Arise in some dark energy theories. Detectable by slow decay back into photons in cavity



Hidden-sector photons

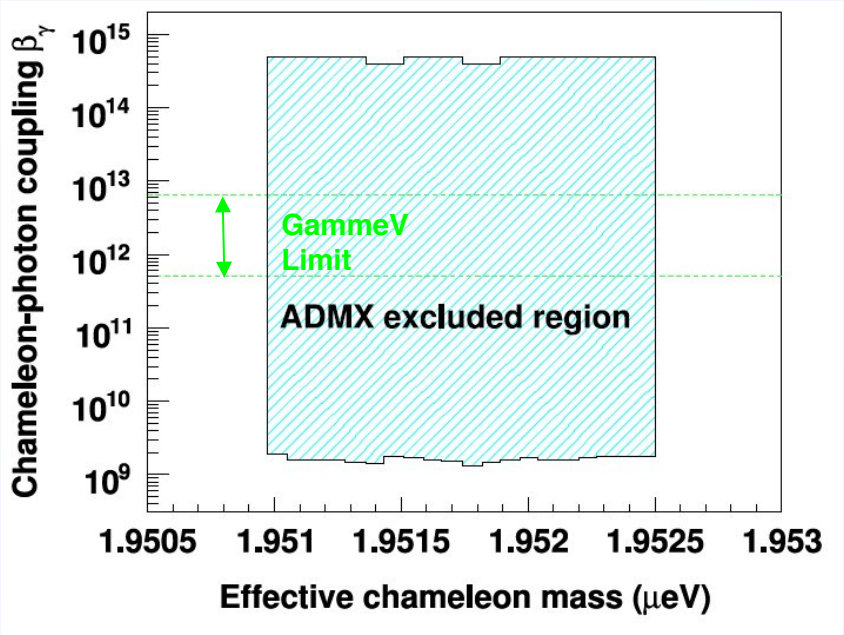
Vector bosons with photon quantum numbers and very weak interactions. Detectable by reconverting HSPs back into photons in ADMX cavity*



Proposed by:** ***Jaeckel & Ringwald (2008)

Phase I operations: ADMX demonstrated to be a versatile detector "Chameleons"& hidden-sector photons (2)

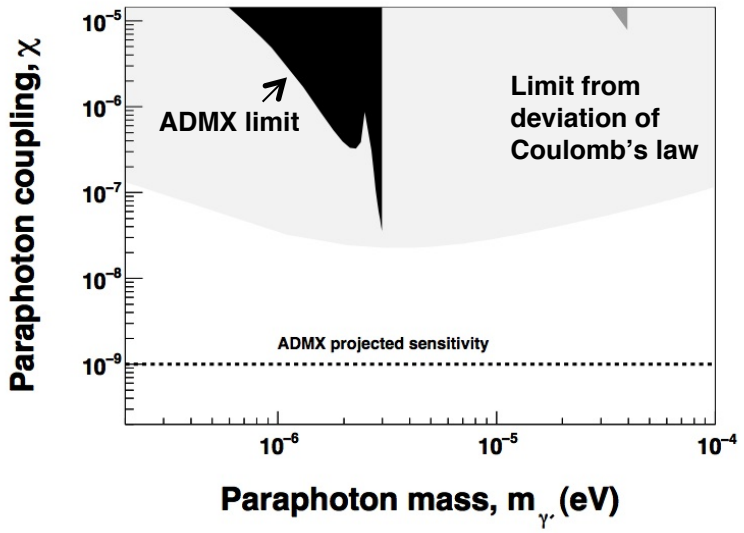
Chameleons



One day of running in June set limits 100 times more sensitive than GammeV experiment.

Published: DOI:10.1103/PhysRevLett.105.051801

Hidden Sector Photons

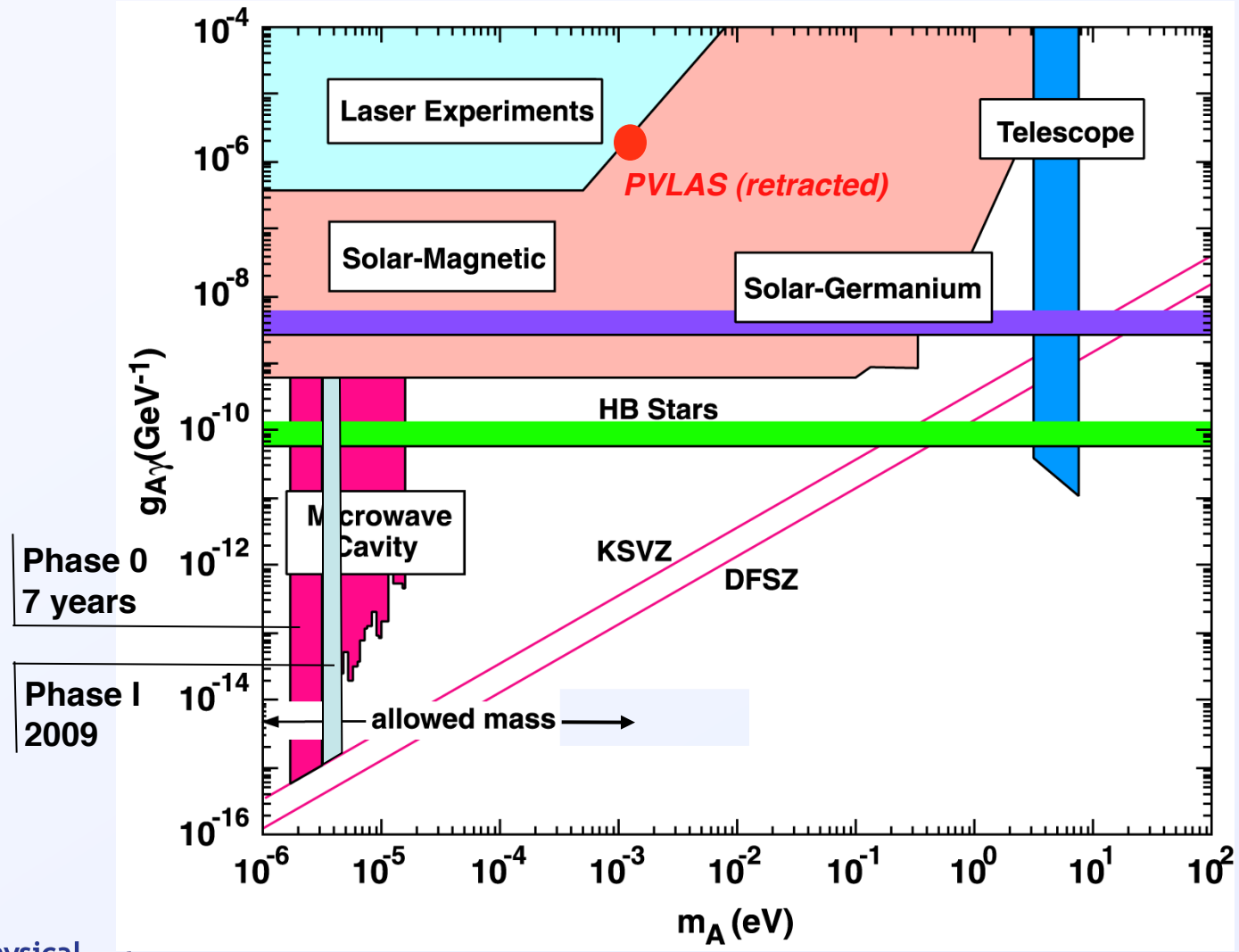


ADMX direct limits on HSP coupling comparable to best indirect search. Next phase projected to extend limits by more than a factor of 10.

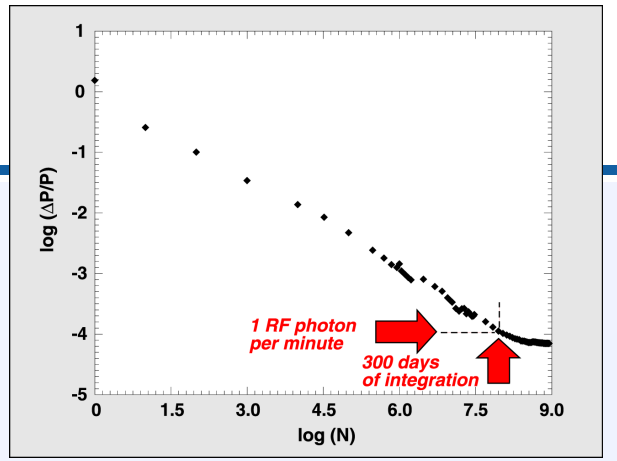
Paper published in PRL.

arXiv:1007.3766v1 [hep-ex]

FY09 Phase I reach



Phase I supplemental operations: Ongoing analysis work for FY '10-11

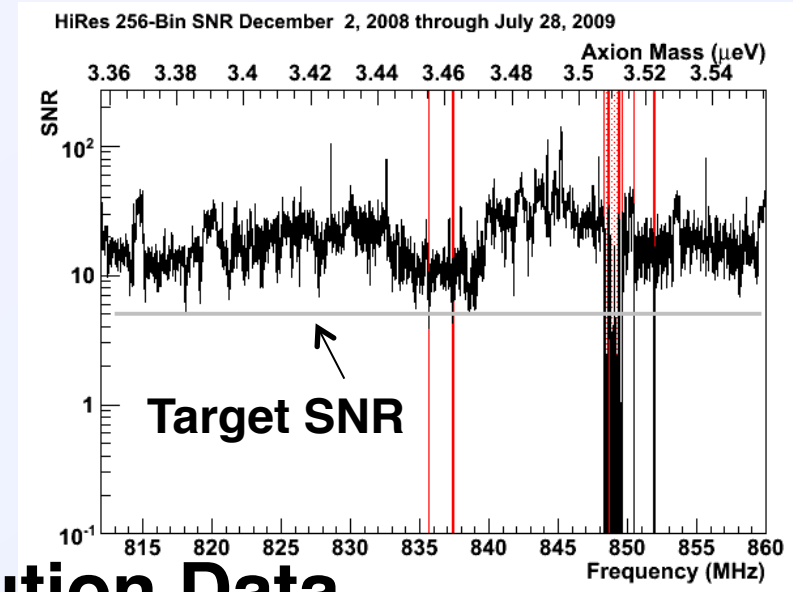


1. Instrumentation Paper.

Description of receiver system with SQUID amplifiers.
Draft close to submission.

2. High Resolution Data

<u>Analysis in progress</u>:
High resolution channel potentially gives greatly increased sensitivity

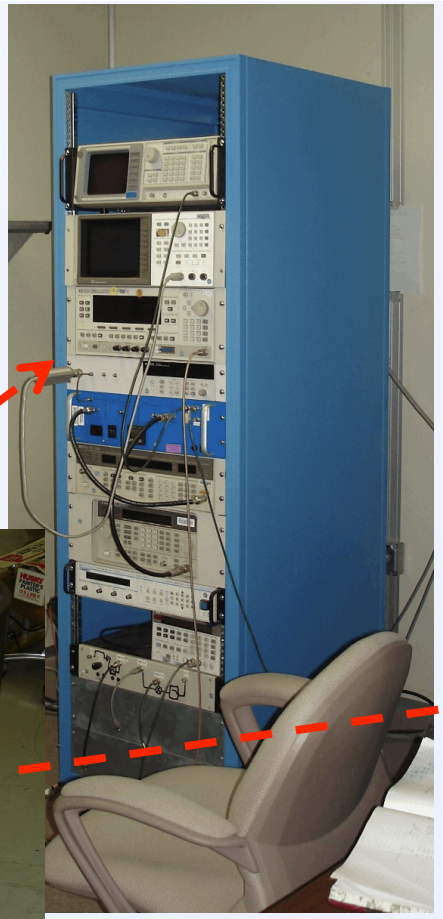


3. Expanded Medium Resolution Data

<u>Analysis in progress</u>: Data above 860 MHz + refined analysis.

Phase I supplemental operations:
Ongoing hardware work for FY '11 to support Phase I analysis

- **Purpose**: Independent RF-receiver chain and scaled down cryostat will allow easier and cheaper testing of components.
  - Current instrument parameters very conservative… additional cryogenic RF instrument studies useful for expanded Phase I analysis
  - Study SQUID / circulator / cavity interactions
  - CAN LEVERAGE FOR PHASE II design & operations
  - Smaller cryogenic space for less LHe use.
  - Can test components while ADMX is running.



Equipment required:

- 1. RF equipment (full receiver chain)
  - Duplicate parts for experiment.
- 2. Small Test Cryostat for components
  - Use Darin's cryostat over in bldg 436.
  - Will need to revamp the dip-probe
- 3. Larger Test Cryostat for cavities (will need to be designed and build).

Current status and near term operations (Phase I supplement)

Funding for FY11: $250k ($91k allocated so far + 16k carryover)

Spent so far: $53k

-$47k: Labor (Carosi, Kinion and support).

-$6k: Travel (conferences, collaboration meetings).

Currently have ~$213k remaining for FY'11

Current Schedule for remaining Phase I tasks:

Instrumentation Paper: Submission by end of Feb (draft with collaboration)

Hi-Resolution Paper: Submission slated for late spring

Expanded Medium-Resolution Paper: Submission slated for late summer/fall

RF-Test stand: Design (mid March)

Procurement of components (April)

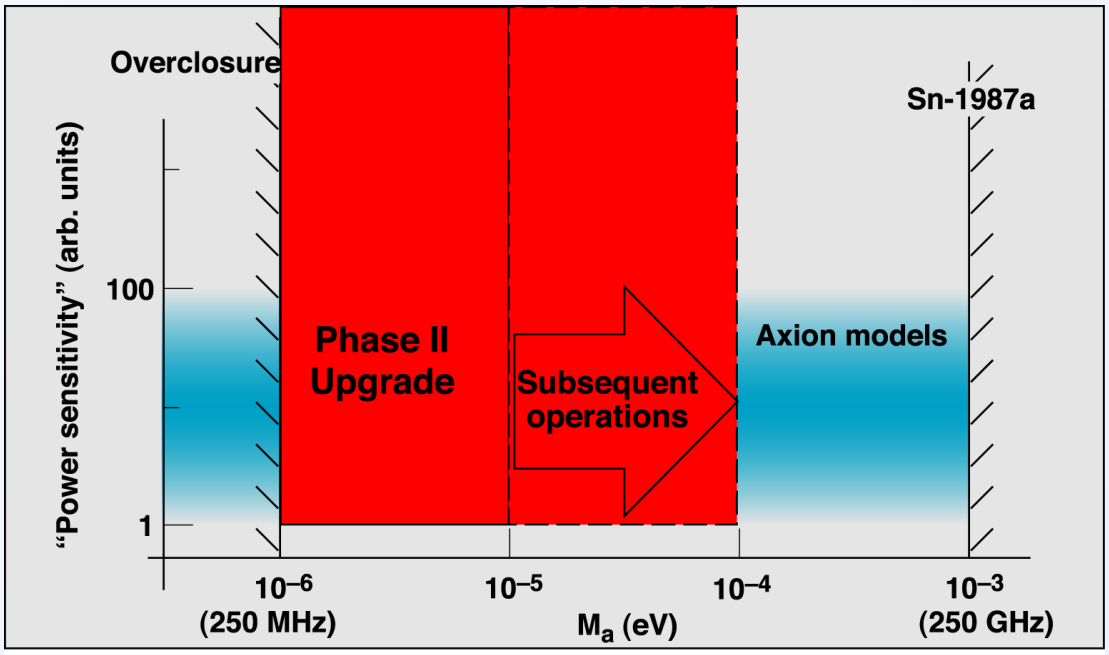
Construction (May-June)

Begin instrumentation studies over the summer (support Phase I analysis).

ADMX Phase II:
Moved ADMX main magnet and insert to the U. of Washington

THANK YOU to DOE-HEP for help in guiding the equipment over the various bureaucratic hurdles!

Phase II ADMX: Add dilution-refrigerator cooling



Phase II will scan the lower-mass decade at or below DFSZ sensitivity, then continue upward in frequency

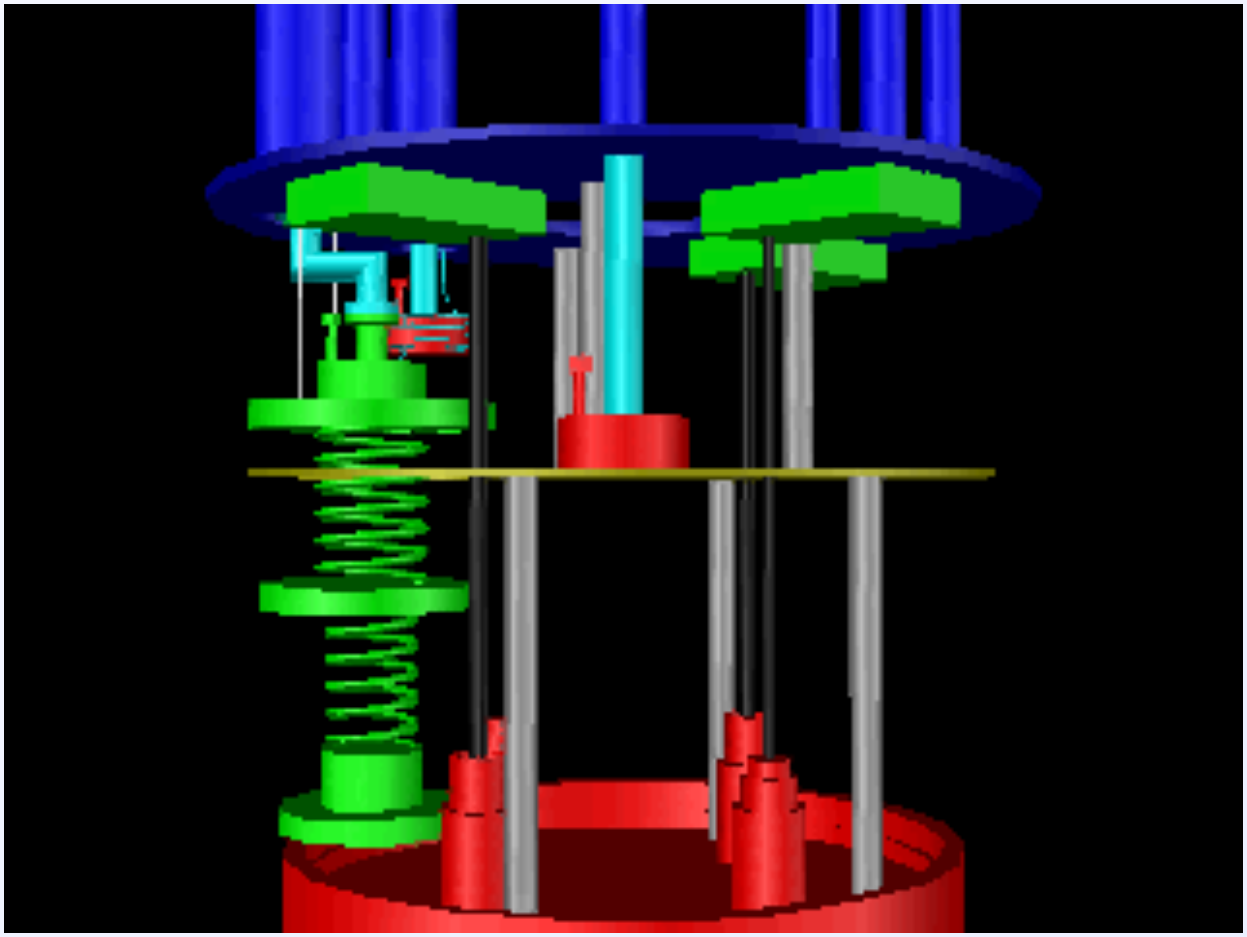
This is the "definitive" search

Phase II ADMX in the PASAG Report November 2009

3.5 PASAG Specific findings and recommendations. … ADMX completed phase-I construction and is operating well. It is estimated to take a total of 1-2 years to cover 10^{-6}-10^{-5} eV down to the first of two model benchmark sensitivities (KSVZ). Phase II of the experiment will cover the same range down to the lower model (DFSZ). This phase requires a dilution refrigerator to go from 1.7 to 0.2 K. This is a unique experiment, and its continuation through phase II is supported in all budget scenarios.

Phase II design work has started…

Preliminary design of dilution fridge placement



ADMX Phase II - LLNL role (Gianpaolo Carosi & Darin Kinion)

1. Cavity plating (Carosi)

Oversee plating of cavities and tuning rods at either LLNL or SLAC.
Test RF response of cavity at LLNL with cryogenic test stand.
Difficult to achieve very low RF surface resistance at 100 mK over such a large area.

2. RF Test Stand (Carosi)… leveraged from remainder of Phase I.

Design and construct an RF test stand that can be used to test cryogenic components without cooling entire experiment (save $$ in LHe) as well as run in parallel with data taking (save Time = save $$)). Operate test-stand in component / system testing.

3. Noise-temperature Calibration (Kinion)

Design, build and commission an *in situ* noise temp. and power calibration system.

4. R&D on piezo-electric drive system

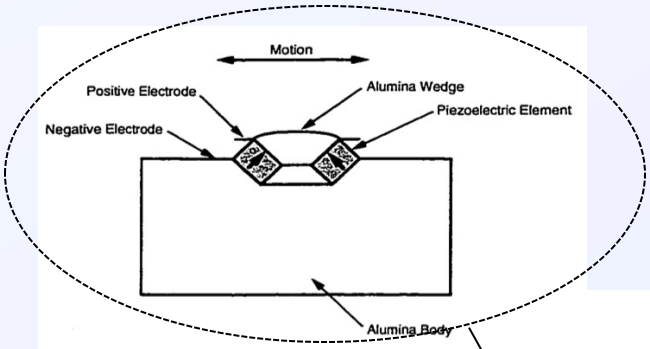
System would greatly decrease thermal loads into cavity & increase tuning accuracy.
Challenging to get to work at low temp & high magnetic field.
Will work with team of Harvey Mudd College engineering & physics students to design, construct and test a piezo-electric drive system. ← Supported directly by LLNL!

Phase II R&D currently being done by undergraduate team Harvey Mudd College Clinic Program (LLNL sponsored)

Replace current gear system with piezo-electric drive.

Advantages:

- **Eliminates the need for large mechanical connections to 300K. (potentially a large problem when dealing with 100 mK systems).**
- **Highly reproducible (step size < 100 Hz).**
- **Potentially much quicker rotation speed.**

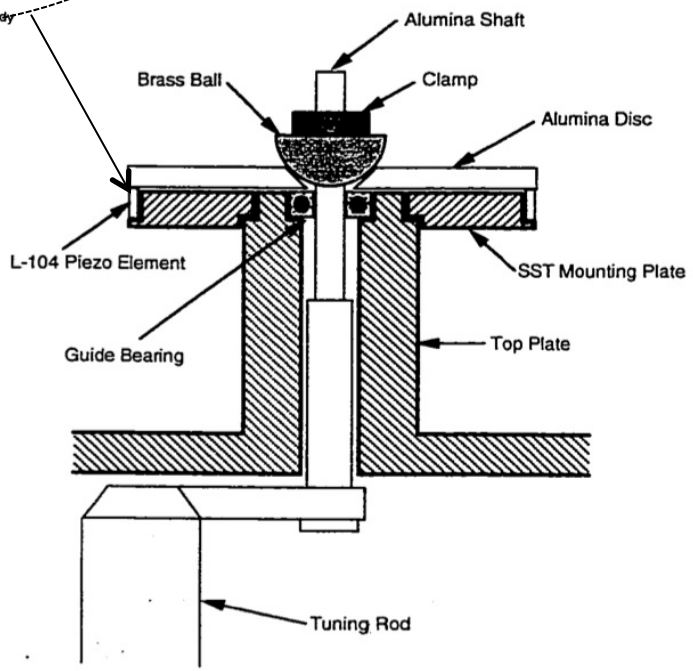


Previous incarnation of piezo-electric system (Darin Kinion's Thesis - 2001):

Suffered from electronic issues and non-uniform stepping due to sharpening of the mechanical resonances at low temps.

Technology has improved since then.

Right size for a team of 4 senior engineer / physics majors.



Currently PAID FOR BY LLNL LDRD (Thanks to Adam Bernstein)!!!!

Physical and Life Sciences

Summary

- **Successfully operated SQUID amplifier near 7 T B-field at pumped LHe temperatures (~ 2 k).**

- **Took Med. Resolution data at KSVZ sensitivity (812-860 MHz):**
  1. **Dark matter axion medium resolution search. PUBLISHED!**
  2. **Chameleon search: Proof of Principle. PUBLISHED!**
  3. **Paraphoton search: Proof of Principle. PUBLISHED!**
  4. **Receiver / Instrument paper: (currently in draft).**
  5. **Ongoing analysis with Hi-Res channel (currently in draft).**
  6. **Upcoming Medium resolution extended analysis.**
  7. **Construction of RF test-stand planned.**

- **ADMX main magnet is now at the U. of Washington (and tested at full strength)!**

- **Phase II design work has been started.**
  - **LLNL will play a prominent role in the Phase II!**
    - **Cavity development**
    - **Noise-temperature calibration**
    - **RF test facility**
    - **Piezo-electric drive system (HMC clinic team) ,← Currently LLNL sponsored (future DOE??)**

  ADMX Collaboration and community eager for Phase II to begin!

Thank you to DOE-HEP for their ongoing support of ADMX!